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IMPORTANCE OF PERIODICAL EXAMINATION AND MAINTENANCE OF PROPELLERS FOR ENSURING SEA-WORTHINESS OF CARGO VESSELS

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ABSTRACT

A vessel as defined by COLREG, is operating in international waters with the assumption that it complies with international conventions adopted by the Flag Administration where it has been registered. In this regard vessels are periodically evaluated by Classification Societies recognised by the Flag, which confirm the fitness for operation of the vessel hull, installation, machinery and equipment. This is also the case of the vessel`s propeller, a vital component responsible for moving the ship, thereby directly contributing to its seaworthiness. Propeller and Shaft are subject to periodical surveys, where a different type of assessment is carried out in connection with the vessel age, CSSC Certificate cycle and operational parameters. Any malfunction of the propeller is to be identified in due time and to be rectified by approved procedures in order to avoid unwanted casualty in operation.

Keywords: seaworthiness, propeller, periodical survey, maintenance

1. Introduction

The characteristic of a vessel seaworthiness is an assumption rooted in sailing tradition from the Middle Ages, outlining the responsibilities of the vessel`s owner towards ensuring the cargo with an amount of guarantee. With years passing, the concept gained distinct particularities throughout international legislation on behalf of maritime transport, while governments endorsed Hague Rules, Hague-Visby Rules and Hamburg Rules, as mandatory applicable conventions. [1] From a legal standpoint, seaworthiness of a vessel engaged in international waters sailing is a liability threshold of the vessel`s owner for obtaining insurance of the vessel, cargo, crew and environment. Even so, giving the multiple shareholders involved in the shipping industry and the diversity of operations, the concept of seaworthiness can hardly be assessed as an absolute notion. In other words, seaworthiness of a vessel is a relative concept, highly dependent on the context. For instance, a bulk carried can satisfactorily meet the technical and procedural requirements stipulated by SOLAS 1974, ICLL 1966, Tonnage 1969, STCW, MARPOL 1973 for safety of navigation, but could be prohibited for carriage of grains due to the coating and cleaning condition of the cargo holds. Hence, in this context, the charterer might consider the vessel as unseaworthy for the scope of contract, due to insurance policy.[2]

Nonetheless, from a technical perspective, ship seaworthiness unfolds on matters related to hull, machinery and installations equipped onboard and their physical and operational condition, extending to the scope designed, constructed and registered. [3] Hence, from the early design stage to commissioning and during the vessel`s operational life, the physical condition of the vessel is to comply with the Statutory regulation from the Flag Administration where the vessel is registered, which bears the responsibility of compliance with international conventions. Furthermore, as stipulated by Reg. 3-1 of SOLAS II-1, each vessel has to compulsorily comply with the Classification Rules of one Society recognised by the Flag Administration.[4] In respect of that, the Classification Society is carrying out periodical surveys for evaluation of the hull, machinery, electrical installation and equipment condition, based on thorough sets of Rules. Satisfactory compliance with international conventions and classification regulation is a hold point in ensuring seaworthiness of a vessel and is carried out and confirmed for vessels under operation under regular predefined intervals.

As it has been briefly pointed out, the complex overall understanding of the seaworthiness notion is challenging and difficult to be dully comprised through technical matters only. Even so, the aim of the current paper is to point out the importance of periodical examination of machinery items in a marine vessel, namely assessment of the propeller, within the context of ensuring seaworthiness.

2. Contextual problematic description

Under the provisions stipulated by Chapter I Reg. 10 from the SOLAS Convention, machinery components involved in producing thrust force are to be subjected to periodical examination. This is also the case of the propeller and propeller shaft of the vessel, considered to be fit for use after satisfactory completion of periodical survey and validation of Cargo Ship Safety Construction Certificate (CSSC). In this regard, bottom examination of the ship together with propeller examination is to be carried out at least two times during the 5 years validity of the CSSC Certificate. However, provided that extensions might be granted by Flag Administration, it is noteworthy to mention that examination of the vessel bottom and immersed installations must be carried out within an interval not longer than 36 months. [5] [6] [7] [8]

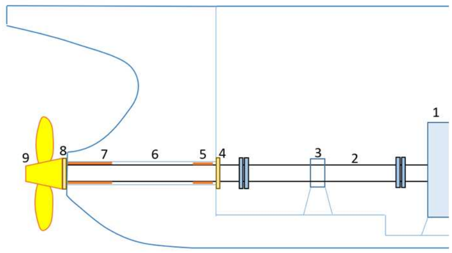


Figure 1 Simplified schematic of power transmission of a cargo vessel (1 Main Engine, 2 Intermediate Shaft, 3 Intermediate Shaft Bearing, 4 Stern Tube Fore Seal, 5 Stern Tube Fore Bush, 6 Tail Shaft, 7 Stern Tube Aft Bush, 8- Stern Tube Aft Seal, 9- Propeller)

It is important to mention that different verification points are established for propeller and propeller shaft, depending on the constructive design of each system. Under this framework, IACS Unified Requirement Z21 depicts a common understanding of the main propeller shaft types and provides general instructions for interested parties regarding regular maintenance protocols. [9] However, as stated by Bielawski, particular attention through condition monitoring is given to the propeller shafts by Classification Societies.[10] Figure outlines propeller shaft types and propeller connection, as described by ClassNK Rules. Furthermore, for each type of the below depicted propulsion machinery, a maintenance scheme is applied and performed under each 5-year cycle of validity of CSSC Certificate.

According with the propeller connection type and lubrication method applied in the stern tube, one of the below mentioned propeller shaft surveys is to be regularly applied: Ordinary Survey/ Simplified Survey/ Simplified Partial Survey.[11]

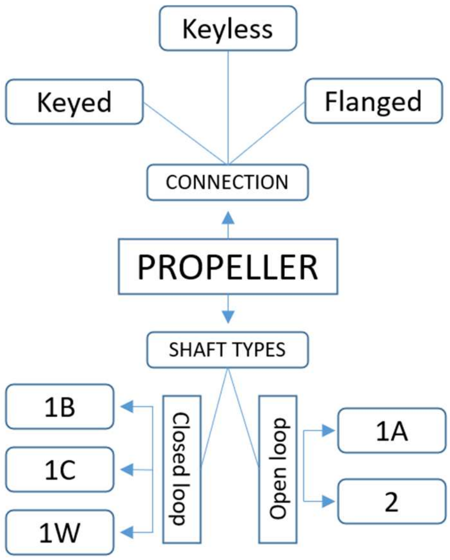


Figure 2 Propeller shaft and propeller connection types, adapted from ClassNK TEC-1277 [11]

It is noteworthy to highlight that Ordinary Survey is the most complex maintenance scheme and it involves complete extraction of the propeller and propeller shaft. Under normal operational condition, if chemical analysis of the lubrication oil is compliant with acceptable limits, wear down of propeller shaft bearing does not exceed 0.3 mm increment between two consecutive measurements and temperature records inside stern tube are not exceeding manufacturer indication [8], this maintenance scheme is applied once in 5 years for propeller shaft type 1A and once in 15 years for type 1B, 1C respectively 1W. However, it is acceptable to carry out tail shaft extraction once in 15 years, provided that Partial Survey with propeller removal is performed on 5 yearly bases, or at least Simplified Partial Survey is attained [11].

3. Propeller condition assessment

Additional verification points are established for the propeller itself despite any of the aforementioned survey type. With respect to IACS UR Z3, close up examination is to be performed for the propeller, exposed part of stern tube bush, sealing glands, fastenings and clearances.[12] Of particular importance is the surface of the propeller. Although most of the commercial vessels are equipped with Nickel Aluminium Bronze (NAB) propeller, material with augmented performance in the harsh marine environment due to its commendable corrosion and wear resistance [15], propellers are still prone to biofouling attachments. Under this unwanted reality, propeller efficiency is adversely affected. Starting from the surface roughness determined by the barnacle adhesion, Wang et all. performed CDF numerical simulation in order to evaluate the negative impact. However, it has been noticed that flow separation and horseshoe vortices appear on the surface contaminated with biofouling, leading to a decrease of the propeller efficiency up to 40%.[13] To efficiently counter the deleterious effect of barnacles upon the hydrodynamic efficiency of the propeller, maintenance works are carried out during periodical surveys by mechanical polishing of the blades surfaces, as highlighted in figure 3.

Figure 3 Underwater mechanical polishing on NAB propeller of biofouling, during in water survey [14]

While providing the thrusting force for vessel motion, the propeller is prone to degradation, under the individual or combined effect of multiple factors, hindering capabilities such as: structural integrity, material characteristics, hydrodynamic efficiency. Under this condition, coupled with the overall impact of the damage suffered by the propeller, an explanatory sketch is depicted in figure 4, for emphasising causal factors in propulsive equipment degradation, as adapted from Chmiel.[17]

For the reason that any damage suffered by the vessel propeller will inflict certain amount of modification in the operational parameters, it is essential to ensure a thorough understanding of casualty origin, in order to restore the equipment to full operational condition by a customised methodology. While not every localised minor damage might represent a threat for the structure of the propeller, remedial action is recommended shortly after the identification of the situation as a countermeasure for potential increased future effects and costs. Recent studies highlight that the complex microstructure of the NAB material from ship propellers is preferentially affected by corrosion phenomenon. Hence, some of the NAB phases are more reluctant to degradation through corrosion than others, leading to a gradual material loss. [16]

In the absence of timely rectification measures, the propeller is exposed to deep wear because of material loss, and repair techniques entail expanded costs and complicated procedures. Additionally, in case of large scale and volumetric damages, propeller balancing is affected, thereby potentially causing noise and vibration in the vessel`s hull, while transmitted through the tail shaft. Although the immediate effect is translated into enlarged discomfort in the accommodation area, for long term period, the vibration caused by a damaged propeller can generate malfunction of other machinery equipment fitted in the engine room. Furthermore, as a common practice, while a vessel is underway with cargo, docking for repairs is not possible, so temporary measures are applied.

In such a context, when a blade lost a part of the tip, underwater operation with diving companies are carried out and the technological removal of a part from the opposite blade is performed, for partially restoring the propeller balance, with the ultimate cost of a reduction in the vessel speed.

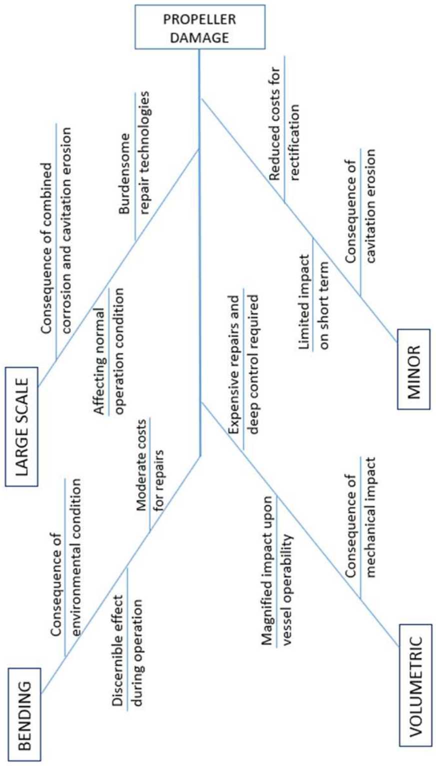


Figure 4 Main types of damages occurring for marine propellers [17]

4. Damage rectification methodology

Case by case, whether damages involving missing parts or areas affected by cavitation erosion are identified during periodical surveys of marine propellers, repair procedures are to be performed. Even so, as stated by Carlton, removal of damages by welding is to be addressed with utmost care, because of the residual stress locally induced in the casted NAB, by thermal processes. [18]

Despite the risks associated with welding processes on NAB substrate, situations such as broken parts of blades or crack occurrence are to be rectified. Due to the high complexity of this alloy and because the propeller is an equipment constantly operating in a highly demanding environment, thermal techniques are to be carried out by specialised service companies, approved by Classification Societies, under the careful attention of qualified personnel who uses techniques and procedures priorly approved.

IACS issued UR W24 under the scope of providing a common accepted methodology for welding works on copper casted propellers.[19] For instance, a cargo vessel equipped with a single fixed pitch propeller with a low skew angle can undergo repair works only for the areas marked as C and B, as pointed out in figure 5. As about surfaces described by A zone, current Rules do not accept any welding works, thus the zone is considered the most vulnerable of the blade. Residual stress arises in the vicinity of the root contour when the propeller is highly loaded under operation. This leads to an expanded risk for occurrence of fatigue cracking. Furthermore, because in this area material thickness has the highest values, blade is more rigid, thereby stress concentrators might determine crack occurrence and propagation.[20] The middle region of the blade, marked as B area, is considered as having a moderate stress magnitude and welding works can be allowed subject to Classification Society approval. Even so, before welding is commenced, during the process itself and after welding, heating of the NAB propeller is a mandatory operation. Controlled heating and cooling of the material have a critical importance in the context of microstructural growth and recrystallization of the material from the molten pool, as the residual stress is decreased and defects such as pores and cracks can be prevented.

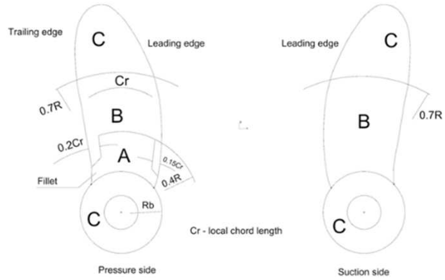


Figure 5 Low skew propeller severity areas adapted from UR W24

Typical welding techniques recommended by IACS for propellers consist in metal arc welding by coated electrodes and gas shielded metal arc process. Although TIG techniques might emphasize the quality of the deposed layers, because of the higher specific heat of this process, procedures do not recommend this methodology, due to the high thermal conductivity of the Cu rich matrix of the propeller material. [19]

Under the framework of challenging classic repair techniques commonly accepted by the industry, a novel state of the art technology for reconditioning the surface of marine propellers is taking shape, namely laser cladding. Throughout this method, material properties like microhardness, corrosion resistance, wear resistance, cavitation resistance can be improved, by obtaining strong bonded coatings with highly alloyed filler material. In this regard, research has been conducted and successfully validated the applicability upon NAB marine propellers. However, although the process of laser cladding is used with successfully results in the aerospace industry, for the marine sector is still a newly explored field. Until completely approved on regularly basis by Classification Societies and transferred to the industry stakeholders, laser cladding of NAB material remains an open path for further development.[21]

5. Study cases

Lately, reports have been published on behalf of commercial vessels casualty subject to propeller failures. Hence, increased expenditures and marine pollution occurred due to the lack of thorough procedural follow up.

In accordance with USCG findings of concern published in 2023, one U.S Flagged Freight Ship faced unexpected decrease in manoeuvring capability while moving in Lake Huron. As a result of investigations, it has been ascertained that further to a brittle fracture which occurred over one former repaired area within zone A and B, a large part of the blade was lost. Furthermore, due to the contact of the broken part, another blade of the propeller suffered a fracture.[22]

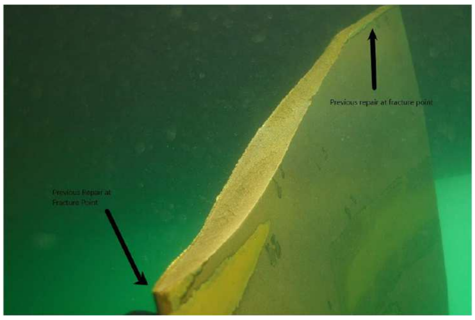
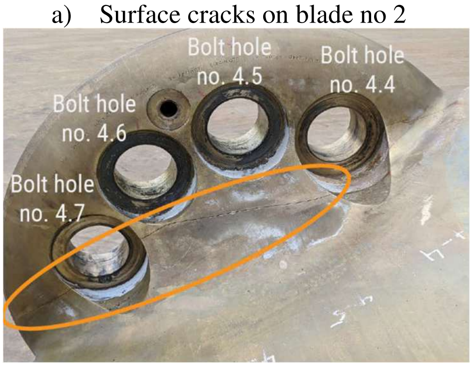


Figure 6 Fractured blade reported by USCG in the vicinity of old repairs [22]

The results of situation assessment depicted lack of evidence in traceability of repairs. Additionally, because of unapproved repairs carried out at some point in the life of the propeller outside the areas where thermal techniques are permitted, residual stress was generated leading to material failure.

Propeller damage was reported also for US flagged container vessel Maunalei in 2022, as described by USA National Transportation Safety Board. As presented in the investigation report, unexpected loss of propulsion occurred for the vessel due to lubrication oil leak in the controllable pitch propeller system. Despite the best efforts of the crew, the situation could not be rectified on board and the vessel commenced dry dock for the evaluation of damages and restauration of the system. However, during close up examination of the propeller in dry dock, it has been ascertained by the responsible Classification Society and Coast Guard inspectors that leakages occurred because of fractures of the propeller material in the hub of two blades, in the vicinity of bolts, as depicted below in figure 6.

a) Surface cracks on blade no 2



b) Cracks in way of bolts

Figure 7 Propeller failure due to cracks, as reported by investigation assessment [23]

As a result of the investigation consisting in mechanical tests, chemical composition test and FEM simulation, it was concluded that crack fracture occurred due to material high cycle fatigue and because of lack of meeting propeller manufacturer design specification for bolt hole counterbore radius. [23]

6. Discussion and concluding remarks

The problematic of periodical examination of the marine propeller and propeller shaft has been presented and analysed in the context of international conventions and IACS recommendations. Because propulsion of a ship engaged in international voyages is vital for its seaworthiness, it was clearly emphasised that there is almost no space for error on the matter, without exposing the ship to high risks. Even so, as depicted by the cases brought to attention, in the reality of vessel operation, casualty might occur, despite the coupled efforts of the vessel owner, Classification Societies and Flag States for ensuring safety on board. Although for the cases under discussion no human life was lost, root cause analysis depicted how a minor issue can lead to expanded costs, up to the extent of millions of dollars.[23]

With respect to the NAB material used on large scale for marine propellers, it can be highlighted that compliance with recommendations for reconditioning is compulsory, due to the complexity of microstructural characteristics of the alloy, which can lead to failure. Hence, during dry dock operations, propeller examination and maintenance play a pivotal role for preserving seaworthiness of the vessel.

Maintenance of marine propellers is constantly developing with research advancement and implementation of time friendly procedures. As the technical requirements have a steady character, the cargo market is very dynamic and exposes the stakeholders to challenges in terms of compliance with periodical surveys schedule. Even so, maintenance of underwater machinery might solve partially the time and funds consuming docking operations.

Future research will focus on developing the novel methodology of NAB marine propellers reconditioning by employment of modern technic of laser cladding.

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